$$I = \frac{M}{V}$$

where $M$ is magnetic moment developed in magnetic specimen of volume $V$. It's S.I. unit is also A $m^{-1}$.

- Magnetic Induction ($B$) is defined as the number of magnetic lines of induction crossing per unit area normally through the magnetic substance, and is given by

$$B = \mu_0(H + I)$$

It's S.I. unit is Tesla T.

- Magnetic Susceptibility ($\chi_m$) of a magnetic substance is defined as the ratio of the intensity of magnetisation $I$ to the magnetic intensity $H$. *i.e.*,

$$\chi_m = \frac{I}{H}$$

It measures the aptness of a magnetic substance to acquire magnetism. It is unitless constant of magnetic substance.

- Magnetic permeability ($\mu$) of a magnetic substance is defined as the ratio of magnetic induction $B$ to the magnetic intensity $H$ *i.e.*,

$$\mu = \frac{B}{H}$$

It is the ability of a magnetic substances to permit magnetic field lines to pass through it. It's S.I. unit is $TmA^{-1}$.

- Relative magnetic permeability ($\mu_r$) of a magnetic substance is defined as the ratio of its magnetic permeability to the permeability of free space *i.e.*,

$$\mu_r = \frac{\mu}{\mu_0}$$

It is unitless constant of magnetic substance.

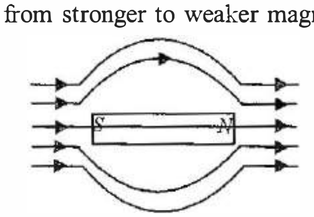
- Relative permeability $\mu_r$ and susceptibility. $\chi_m$ of a magnetic substance are related as

$$\mu_r = 1 + \chi_m$$

- Magnetic materials are classified into the three types.

**Diamagnetic substances** are those which when placed in a magnetising field are feebly magnetised in a direction opposite to that of the magnetising field.

  - It is feebly repelled by a magnet
  - When suspended freely inside magnetic field, it sets itself slowly at right angles to the direction of field.
  - When placed in non-uniform magnetic field, it tends to move from stronger to weaker magnetic field.



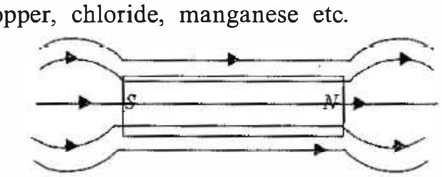

  - It has small and negative value of magnetic susceptibity $\chi_m$.
  - It's relative magnetic permeability $\mu_r$ is just less than 1.

    Ex. Copper, zinc, bismuth, gold, silver, lead, water, sodium chloride etc.

**Paramagnetic substances** are those, which when placed in a magnetic field are feebly magnetised in the direction of the magnetising field.

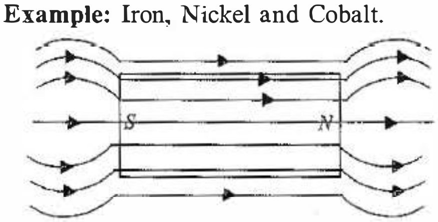
  - It is feebly attracted by a magnet.
  - When suspended freely inside magnetic field, it slowly sets itself parallel to the direction of magnetic field.
  - When placed in non-uniform magnetic field, it tends to move from weaker to stronger magnetic field
  - It has small and positive value of magnetic susceptibility $\chi_m$.
  - It's relative magnetic permeability $\mu_r$ is just greater than 1.

    Ex. Aluminium, sodium, antimony, platinum, copper, chloride, manganese etc.




**Ferromagnetic substances** are those, which when placed in a magnetic field are strongly magnetised in the direction of magnetising field.

  - It is strongly attracted by a magnet.
  - When suspended freely inside magnetic field, it quickly sets itself parallel to the direction of magnetic field.
  - When placed in non-uniform magnetic field, it tends to move from weaker to stronger magnetic field.
  - It has large and positive value of magnetic suspetibility $\chi_m$.
  - It's relative permeability $\mu_r$ is much larger than 1.
  - Ferromagnetism decreases with rise in temperature, and above a certain temperature called 'Curie's temperature' ferromagnets become paramagnets. **Example:** Iron, Nickel and Cobalt.




- Curie's law in magnetism states that magnetic susceptibility of paramagnetic material is inversely proportional to its absolute temperature *i.e.*,

$$\chi_m = \frac{C}{T}$$

where $C$ is called 'Curie's constant'.

## ELECTROMAGNETS

- Electromagnets are made of ferromagnetic materials which have high permeability and low retentivity, such as soft iron. On placing a soft iron rod in a solenoid and then on passing electric current through it, strong magnetic field is produced, and it behaves like an electromagnet. When current is switched off, it losses its magnetisation effectively, as soft iron core has low retentivity.

Further, area under hysteresis loop for soft iron is less. So where repeated cycles of magnetisation occur, there on using soft iron core, energy losses are less. This is why soft iron is used in cores of transformers, galvanometers, generators etc.

- Permanent magnets are made of materials having high retentivity, high coercivity and high permeability such as steel. Other suitable materials for making permanent magnets are alinico (alloy of iron, aluminium, nickel, copper and cobalt), cobalt steel and ticonal.

**Illustration 10**

If the magnetic dipole moment of an atom of diamagnetic material, paramagnetic material and ferromagnetic material are denoted by $\mu_d$, $\mu_p$ and $\mu_f$ respectively, then:

(a) $\mu_p = 0$ and $\mu_f \neq 0$
(b) $\mu_d = 0$ and $\mu_p \neq 0$
(c) $\mu_d \neq 0$ and $\mu_p = 0$
(d) $\mu_d \neq 0$ and $\mu_p = 0$

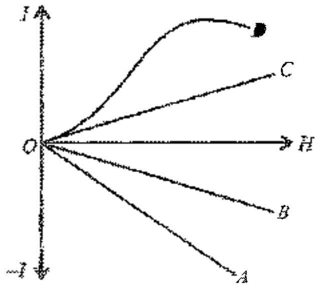
**Soln.** (b) : The individual atoms or ions or molecules of a diamagnetic material do not possess a permanent dipole moment, hence $\mu_d = 0$.

But, the atoms, ions or molecules of both paramagnetic and ferromagnetic materials possess individual magnetic dipole moments, hence $\mu_p \neq 0$ and $\mu_f \neq 0$.

$\Rightarrow$ (b) is correct.

**Illustration 11**

The most appropriate *I-H* curve for a paramagnetic substance is




(a) *OA*
(b) *OB*
(c) *OC*
(d) *OD*

**Soln.** (c) : $\chi_m$ (susceptibility) $= \dfrac{I}{H}$

For paramagnetic substances,

$0 < \chi_m < E$, where $E$ is a small positive number.

Hence $I$ vs $H$ graph is a straight line with a small positive slope or *OC*.

$\Rightarrow$ (c) is correct.